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(Research Article)

Investigation of the effects of fine dune sand on the geotechnical characteristics of lateritic soil

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Abstract

Lateritic gravels are highly favored as a construction material for road pavements in Africa. With the rise in road construction projects and subsequent increase in traffic and overloading, the required physical and mechanical properties of lateritic gravels have become more stringent. However, the desirable qualities of these materials are diminishing, and their exploitation will soon become an environmental problem. This study aims to enhance the physico-mechanical properties of the remaining lateritic gravels by incorporating fine dune sand sourced from Dori, in the Sahelian region in Burkina Faso. This lithostabilization was made by formulating mixtures with varying proportions of fine sand (10%, 20%, and 30% by weight). Then, the influence of sand content on the physico-mechanical behavior of lateritic gravels from two sites (Kamboinsin and Saaba) was examined. Results indicate a significant reduction in the plasticity index and an increase in optimal dry density with the addition of sand. Moreover, the California Bearing Ratio (CBR) index substantially improves, particularly with 30% sand content, making laterite from Saaba (LS) suitable as a base layer for road pavement according to CEBTP standards.

Keywords: Road Pavement; Lateritic Gravel; Lithostabilization; Fine Dune Sand; Physical-Mechanical Properties.

1. Introduction

Laterites, found at low depths in soils, are widespread across the intertropical regions of Africa, including Burkina Faso. These soils result from intense, deep, and ancient weathering processes of various rocks, characterized by significant residual accumulations of clay and metal hydroxides [1]. They often exist in the form of hard crusts, indurated laterites, and loose gravels. Due to their ease of extraction, laterites are commonly used in constructing road base and subbase layers [2]. However, specific requirements must be met to ensure the durability, stability, and overall performance of the pavement.

In Burkina Faso, lateritic gravels are frequently used for road base layers due to both economic and technical reasons. Nonetheless, their use must comply with stringent properties as prescribed by the Practical Guide for Pavement Design in Tropical Countries (CEBTP) [3]. For instance, to be used as a base layer, lateritic gravel must have a plasticity index below 15 and a CBR (California Bearing Ratio) above 80, according to CEBTP standards [3]. In recent years, the laterites which meet these criteria have been extensively exploited, raising concerns about the availability of quality materials amidst increasing road infrastructure projects. The available lateritic gravels in project areas are often rejected for their poor quality, favoring distant extraction sites which incur significant transportation costs, in terms of economic and

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environmental impacts, for road construction projects. In a study, Lompo demonstrated that the available lateritic gravels in Burkina Faso serve as a raw material for road subbase layers but require improvements for use as a base layer [4].

Several studies in the literature show that the quality of lateritic gravels can be improved using chemical stabilizers such as cement, lime, or bituminous emulsions [5, 6, 7, 8, 9]. However, these materials are often imported, adding to the already high overall costs of road infrastructures, which is a concern for decision-makers. Lithostabilization is proposed in the scientific literature as a cost-effective solution compared to chemical stabilization for enhancing the geotechnical properties of lateritic gravels [10, 11]. This method involves mixing lateritic gravel with a more resilient granular material to strengthen its structure. The commonly used granular materials are gravels obtained by crushing massive rocks like granite and basalt. Although effective, the crushing process incurs additional costs and environmental impacts.

Recent studies have explored using alluvial sand as a stabilizing agent for lithostabilization of lateritic gravels. Madjadoumbaye et al. [12], conducted a study on lithostabilization of laterite in Cameroon using Sanaga river sand. Their study showed that the bulk density of the mixture increases with the addition of up to 35% sand; but decreases beyond this proportion. Ndiaye et al. [13] analyzed the effect of dune sand from Keur Massar (Senegal) on two different laterites, each with a CBR of 70 but with plasticity indices of 22.1% and 16.4%. The dune sand had grain sizes between 0.4 and 0.6 mm. They found that a mass proportion of 30% dune sand is needed for the first laterite and 10% for the second to reduce the plasticity index to the CEBTP-recommended value of the plasticity index of 15% [3]. With these additions, the mechanical properties of the second laterite improved, with its CBR index increasing from 70 to 85 and a plasticity index of 13.1. Conversely, the addition of 30% dune sand to the first laterite decreased its CBR index from 70 to 65 with a plasticity index of 12.9. Okonkwo et al. [14] also worked on stabilizing a laterite with a CBR of 24 using sand. Their results showed that sand is an effective stabilizer for lateritic soil, with the CBR index increasing from 24 to 86 at the optimum content of 30% of sand. These studies indicate that the effect of stabilizing laterite with sand depends on the type of laterite. Madu's study on the improvements of relevant properties of six laterite samples mixed with sand demonstrated that adding sand allows to reduce the liquid limit, optimal moisture content, plasticity index, and linear shrinkage, and to increase the maximum dry density and CBR [15]. Madu found that an optimal sand percentage exists to maximize most measured parameters, and this optimal percentage varies for each type of laterite from 4% to 40%.

In Burkina Faso, the northeastern region, particularly around Dori, has abundant fine dune sand that is underutilized due to its unsuitability for quality concrete. This study aims to investigate the influence of sand from Dori on the geotechnical properties of low-quality lateritic gravels, which are unsuitable for use in road construction.

2. Materials and methods

2.1. Materials

The study is conducted on two lateritic gravels from Kadiogo province in Burkina Faso. One sample was taken from a quarry located North of Ouagadougou in Kamboinsin (LK), which was largely characterized in previous studies [10]. The other sample was collected from a quarry located southeast of Ouagadougou in the municipality of Saaba (LS). Samples were collected from each site and stored in bags for geotechnical characterization in the laboratory.

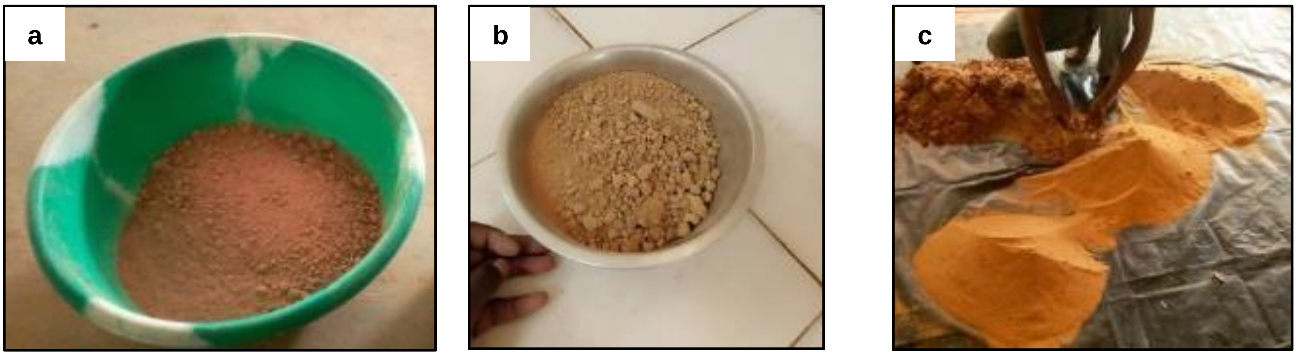

Figure 1 a- Lateritic gravel from Kamboinsin (LK). b- Lateritic gravel from Saaba (LS). c- Dune sand from Dori (SD)

The sand was collected from Dori dunes sand (SD). Dori is in the Sahel region located in northeastern of Burkina Faso and has large quantities of this sand. Samples of the materials are shown in Figure 1.

2.2. Methods

For this study, geotechnical and mechanical identification tests were first conducted on the raw samples. Subsequently, several formulations were made by substituting 10%, 20%, and 30% of the weight of the lateritic gravels from the two quarries (LK and LS) with fine sand from Dori. The samples obtained after formulation were characterized physically and mechanically, and the results were analyzed according to the CEBTP guidelines [3].

A dry sieve analysis was performed on the gravels, fine dune sand, and formulated mixtures to examine the impact of dune sand addition on the grain size distribution of the lateritic gravels [16]. To assess the clay content in the sand, a sand equivalent test was conducted, which also evaluated the cleanliness of the fine dune sand [17].

The specific density of the different materials was measured using an air pycnometer [18]. An analysis of the Atterberg limits of the laterites was carried out on the soil fraction passing through a 0.40 mm sieve to determine the effect of adding dune sand on their plasticity index [19]. The liquid limit and plastic limit of the gravels before and after stabilization with dune sand were thus evaluated. Modified Proctor tests were conducted on the lateritic gravels and the formulated mixtures to evaluate the bearing capacity and optimal moisture content of the material before and after adding fine sand [20]. A CBR test [21] was then performed to implicitly evaluate the effect of adding dune sand on the CBR of the studied mixtures under optimal compaction conditions. In this study, only the immediate CBR was determined, as the study area experiences very little moisture variation.

3. Results and discussion

3.1. Materials characterization

3.1.1. Lateritic gravel

Figure 2 and Figure 3 show the grain size distribution of laterites from kamboinsin (LK) and Saaba (LS), compared to the grain size bands for subbase and base layers prescribed by the CEBTP [3]. LK does not fit in the bands for either subbase or base courses. In contrast, LS fits 100% within the subbase layer band and 60% within the base layer band. However, the percentage of particles finer than 1 mm (41%) in the LS is slightly higher than the recommended value.

Therefore, according to CEBTP [3] guidelines, from the perspective of grain size distribution of natural lateritic gravels, the LK laterite is not suitable for use in either base or subbase layers, while the LS laterite is suitable for subbase layers and marginally acceptable (60%) for base layers.

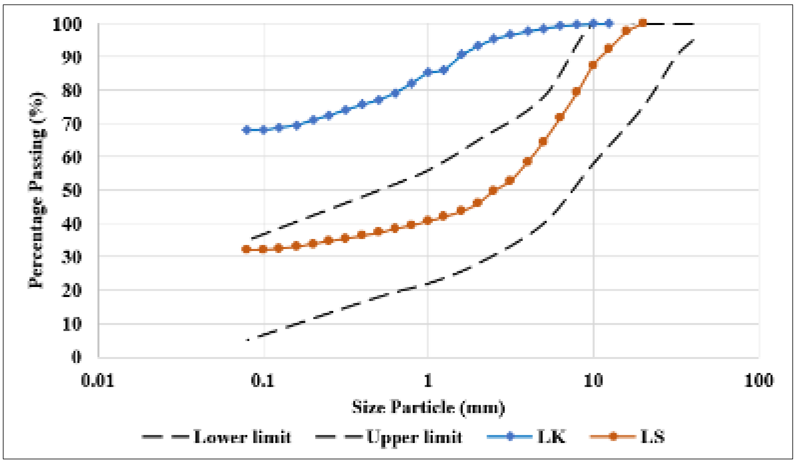

Figure 2 Grain size distribution of LK and LS compared with the CEBTP [3] guidelines for the application in subbase layer

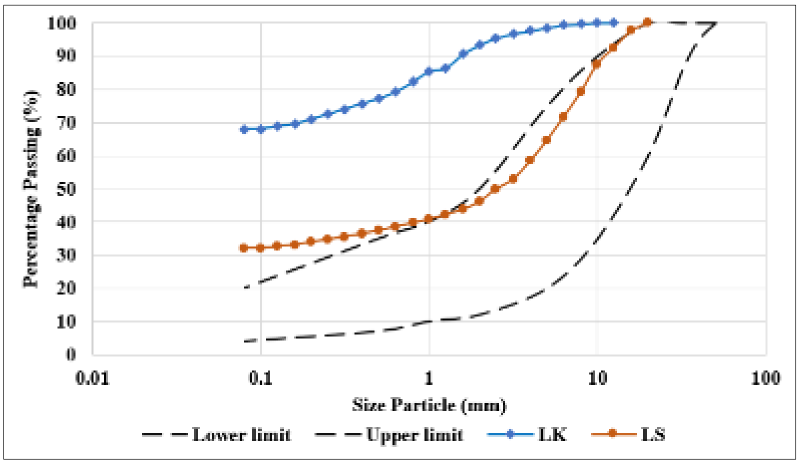

Figure 3 Grain size distribution of LK and LS compared with the CEBTP [3] guidelines for the application in base layer

Table 1 presents the results of the physical and mechanical characterization tests for laterites LK and LS, as well as the values prescribed by the CEBTP [3] for subbase and base courses. The LK laterite is a fine soil with more than 60% passing through a 0.08 mm sieve. It has a plasticity index of 20.42%, classifying it as A-2-7 in the HRB [22] classification (clay soil). It has a dry density at optimum modified proctor (OPM) of 1.69 g/cm^3 and an immediate CBR index of 36.73 at 95% of OPM. According to the specifications recommended by the CEBTP, the LK laterite meets the criteria for subbase layers regarding plasticity index and CBR index; for low-traffic pavement layers. However, it is unsuitable for use as a base layer.

Table 1 Geotechnical characteristics of Kamboinsin and Saaba laterite compared with CEBTP specifications [3]

Sample identification	**Grain size distribution (%)**		**Atterberg Limits**			**Modified Proctor**		**CBR index at 95%**
	0.08 mm	2 mm	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (Ip)	Wop (%)	ρ_d (g/cm^3)	%
LK	68.03	93.28	49.20	28.78	20.42	13.9	1.69	36.73
LS	32.13	46.02	45.24	20.28	24.97	12.9	2.08	41.67
CEBTP Specifications for Low Traffics								
Subbase course	< 35	-	-	-	< 30	-	$1.8 < \rho_d < 2$	> 30
Base course	< 20	-	-	-	< 15	-	> 2	> 60

The characterization results of the LS laterite show that it contains approximately 32% fine particles with a plasticity index of 24.96%. According to the system for Highway Research Board (HRB) [22], this soil is also into the A-2-7 category (silty or clayey gravel or sand). The LS laterite has a dry density at OPM of 2.08 g/cm^3 and an immediate CBR index of 41.67 at 95% OPM. Therefore, it appears to be coarser than the LK laterite, with a higher CBR index, dry density, and plasticity index. According to CEBTP [3] criteria for low-traffic roads, the LS laterite can be used for subbase layers, but its use in base layers requires improvement.

3.1.2. Fine sand

The grain size distribution curve of the dune sand (SD) is shown in Figure 4 and classified as 0/0.5 granular class. It is a fine sand with a fineness modulus of 1.59, exhibiting a uniform gradation with very little amount of clay particles, as evidenced by the 94.16% sand equivalent value (Table 2). The bulk density and specific gravity of the dune sand, as measured by a pycnometer, are 1.47 t/m^3 and 2.56 t/m^3, respectively.

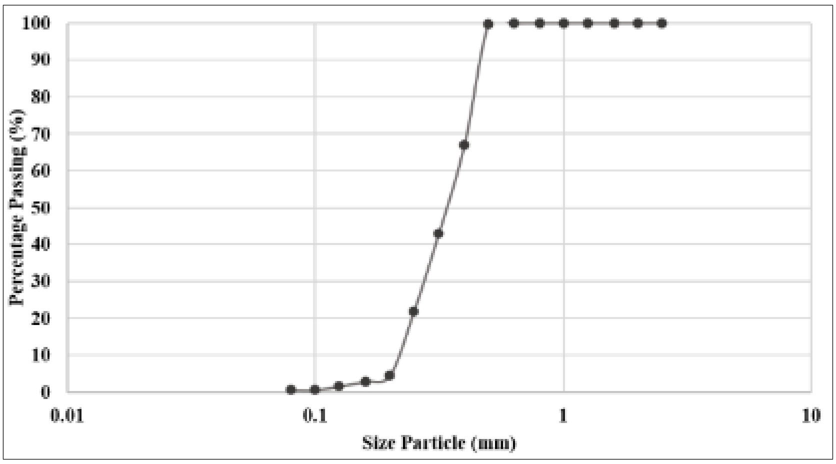

Figure 4 Grain size distribution of sand from Dori (SD)

Table 2 Physical characteristics of dune sand from Dori

Grain size distribution (%)	Fineness modulus	1.59
	Uniformity coefficient	1.74
	Curvature coefficient	0.98
	Passing through 80 µm (%)	0.54
Bulk density (t/m^3)		1.47
Specific gravity (t/m^3)		2.56
Cleanliness (%)		94.16

3.2. Mixtures of laterite and sand

Figure 5 and Figure 6 show the grain size distribution of the untreated and treated laterites LK and LS with 30% dune sand, compared to the grading envelopes recommended by CEBTP [3] for the use of lateritic gravels in subbase and base layers. The addition of 30% dune sand does not allow the grain size distribution curve of LK laterite to fall within the recommended envelopes, but there is an increase in the granular skeleton below 1 mm, indicated by a downward shift of the curve. Specifically, the percentage passing the 0.1 mm sieve decreases from 68% to 48% before and after the addition of 30% sand. However, there is no significant change in the grain size distribution for particles above 1 mm. This suggests that the fineness of the dune sand (0/0.5) does not allow to improve the granular distribution of laterite to include a material outside of the recommended grading envelopes for grain sizes above 1 mm.

For the LS laterite, there is also an increase in the granular skeleton below 1 mm with the addition of 30% dune sand. This increase reduces the percentage of fine particles and improves the inclusion of the grain size curve of LS laterite from 60% to 80% within the recommended envelope for the base layer. This result is consistent with the literature, which indicates that the addition of granular materials to lateritic gravel increases the granular skeleton and decreases the fine particle content [10, 23, 24].

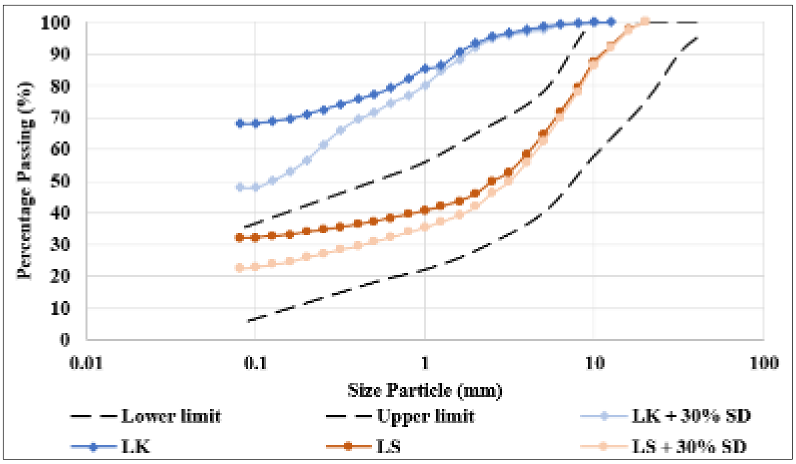

Figure 5 Grain size distribution of the mixtures (LK + 30% SD et LS + 30% SD) and comparison with the CEBTP [3] criteria for application in subbase layer

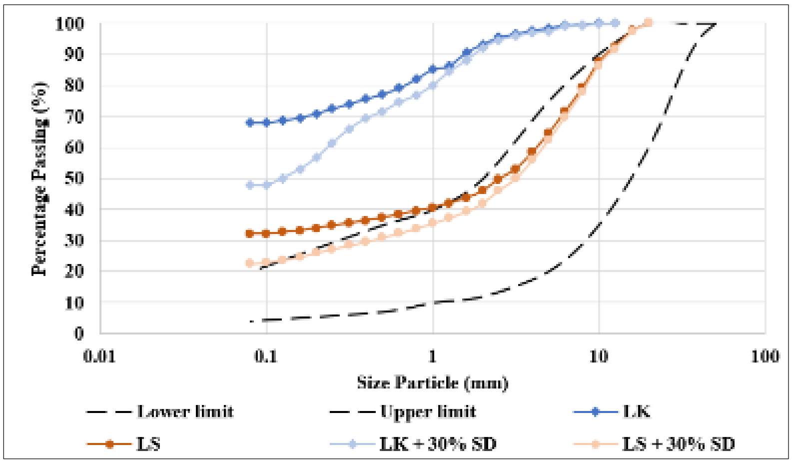

Figure 6 Grain size distribution of the mixtures (LK + 30% SD et LS + 30% SD) and comparison with the CEBTP [3] criteria for application in base layer

The evolution of the plasticity index of the two laterites with the addition of the sand is shown in Figure 7. A decrease in the plasticity of both laterites is observed with the addition of dune sand, becoming very noticeable starting from 20% addition. The plasticity index of the LK laterite decreases from 20.42% to 14.26% after adding 30% dune sand, i.e. a reduction of 30.20%. This index value makes it acceptable for use in subbase layers and also in base layers according to the CEBTP [3] guidelines. For the LS laterite, the plasticity index decreases from 24.96% to 15.80% with 30% dune sand, a reduction of 37%. At 30% improvement, the plasticity index of the LS laterite remains slightly above the recommended value for the base layer. The reduction in the plasticity index of the laterites with the addition of sand is explained by the decrease in the clayey fine particle content, which is replaced by non-clayey fine sand. Ndiaye et al. [13] found similar results with the fine sand of Keur Massar and the laterite of Lam-Lam, where the plasticity index decreased approximately 49%, from 23.2% to 11.8%, with the addition of 30% fine sand. In their study, they found that a content of only 10% sand is sufficient to reduce the index to below the recommended 15% for the Sindia laterite, with a plasticity index of 16.4%.

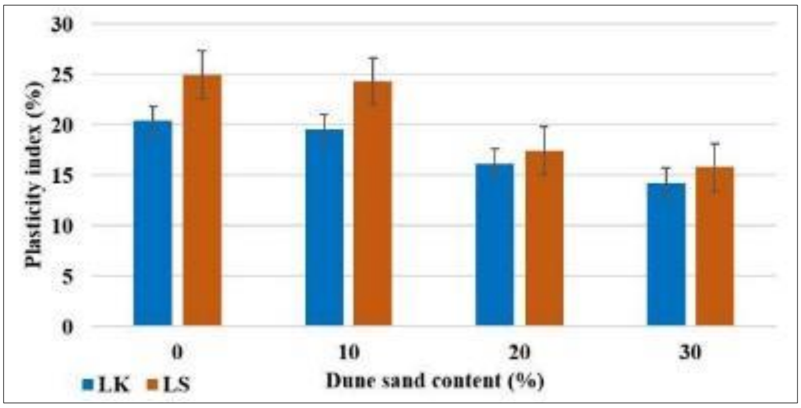

Figure 7 Plasticity index of LK and LS laterites with dune sand content

The results of the modified Proctor tests on the laterite-sand mixtures are presented in Figure 8 and Figure 9 for laterites LK and LS, respectively. While the optimum moisture content of the laterites decreases with the increasing sand content, there is an increase in the maximum dry density with the sand content. For the LK laterite, the density values increase from 1.69 g/cm^3 to 1.8 g/cm^3 after the addition of 30% fine dune sand. According to CEBTP guidelines [3], the obtained density allows this laterite mixed with sand to be considered as suitable for a road subbase layer. For the LS laterite, after incorporating the same proportion of sand, the density values increase from 2.08 g/cm^3 to 2.17 g/cm^3. This density, exceeding 2 g/cm^3, CEBTP guidelines [3], suggests that LS laterite mixed with 30% fine dune sand can be used as a base layer. This evolution of dry density is similar to that obtained by Madjadoumbaye et al. [12] in Cameroon, who found that the maximum sand content for improving the dry density of laterites is 35%. The decrease in optimum moisture content with increasing sand content is likely due to the reduction in clay content in the laterite, characterized by a lower percentage of fine particles [25, 26]. The increase in dry density with the addition of sand is explained by the reinforcement of the lateritic skeleton through the filling of pores with fines during compaction [27].

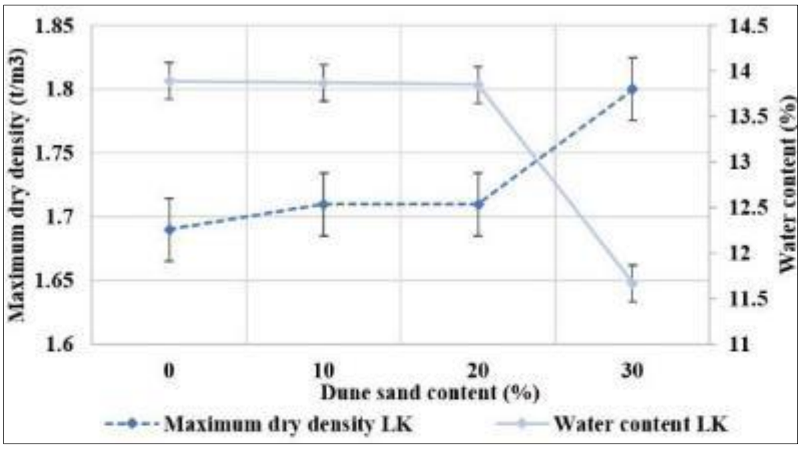

Figure 8 Variation of maximum dry density and optimum water content of LK laterite with the addition of sand

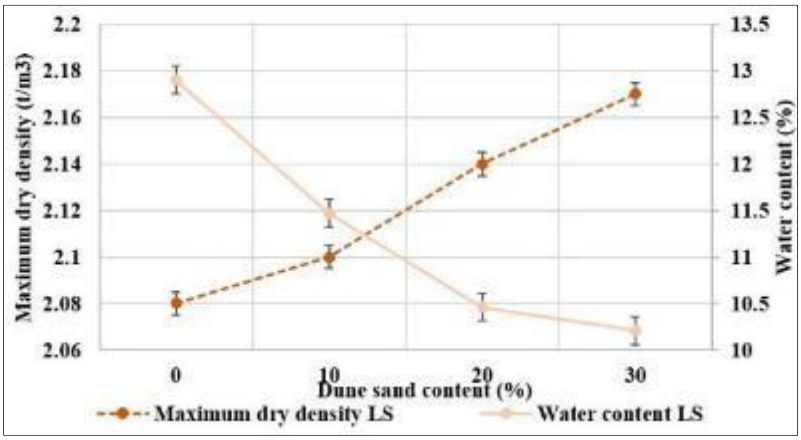

Figure 9 Variation of maximum dry density and optimum water content of LS laterite with the addition of sand

The results of the CBR tests on the laterite and sand mixture, presented in Figure 10 reveal an increase in immediate CBR values at 95% of Optimum Modified Proctor. For the LK laterite, these values increase from 36.73% to 40.03% after incorporating 30% sand. Since this value is below 60%, LK laterite cannot be used in base layers according to CEBTP recommendations [3]. Regarding the LS laterite, the immediate CBR at 95% increases from 41.67% to 68.42% after adding 30% sand. Thus, LS laterite improved with 30% dune sand can be used in base layers. The increase in CBR values with the addition of sand is linked to the increase in maximum dry density and the decrease in clay content in the mixtures [10, 28]. The CBR index increases by 9% for LK laterite and by 64% for LS laterite; when 30% dune sand is added. This is explained by the fact that LS laterite initially had a relatively good grain size distribution, and the addition of dune sand further improved it, as shown in Figure 6 [23]. Furthermore, despite adding dune sand to LK laterite, its grain size distribution curve does not fall within the recommended grading envelopes for subbase or base layers. This negatively impacts the densification of the material during compaction [29].

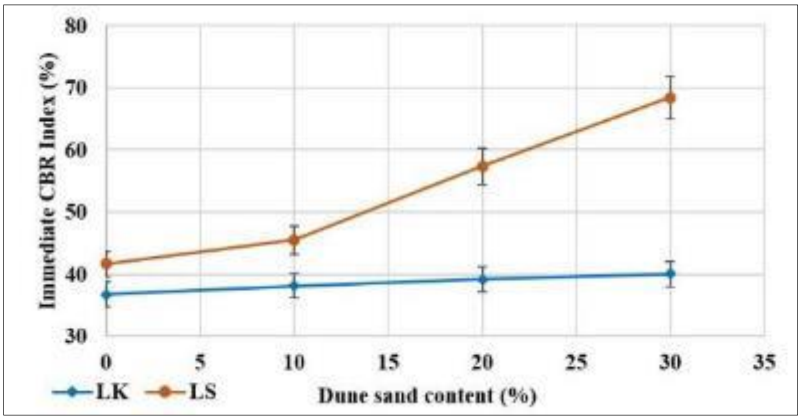

Figure 10 Immediate CBR indix for LK et LS laterites with the addition of sand

4. Conclusion

The present study focused on stabilizing two types of laterites, LK and LS, using fine dune sand. The geotechnical characterization of the laterites showed that LK consists of 68% fine particles (passing through a 0.08 mm sieve) with a plasticity index of 20.42% and a CBR index of 36.73%. The LS laterite is coarser, with 32% fine particles, a plasticity index of 24%, and a CBR index of 41.67%. After adding fine sand, the results conclusively demonstrated its positive impact on the lithostabilization of the studied lateritic gravels. Specifically, the addition of 30% dune sand significantly improved the geotechnical properties of these materials.

The reductions in the plasticity index of 30.20% and 36.70% were respectively observed on the laterites for LK and LS, followed by the increases in the dry density at OPM from 1.69 g/cm^3 to 1.8 g/cm^3 for LK and from 2.08 g/cm^3 to 2.17 g/cm^3 for LS, and the increase in the CBR index by 9% for LK and 30% for LS. This study confirms that, in line with CEBTP recommendations, adding 30% dune sand significantly enhances the physical and mechanical performance of the studied gravels. Remarkably, the LS laterite, initially recommended for subbase layers, proved suitable for use as a base layer after adding 30% sand.

However, to deepen the understanding of the behavior of these materials, further studies could be considered. These would help determine the optimal dune sand content for improving the properties of the gravels. Additionally, an analysis of the Young's modulus would be beneficial to evaluate their response to deformations. Further exploration of formulations could involve combining fine dune sand from Dori with coarser crushed granite to fit the fine lateritic gravels into the recommended granular grading, thus opening new perspectives for using lower-quality gravels in pavement layers.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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